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Prediction of optimal depth for central venous catheter targeting the cavoatrial junction in Korean

한국인에서 대정맥-심방접합부를 겨냥한 중심정맥도관의 깊이 예측을 위한 임상연구

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Abstract

Introduction: Central venous catheters (CVC) should be positioned at the cavoatrial junction (CAJ) or the right atrium. If catheters are inserted to a depth derived by adding the distance between the skin insertion point and the clavicular notch and the distance between the clavicular notch and the carina, the catheter tip can be placed near the carina. Based on that, this study aims to make a formula to place a catheter tip near the CAJ.

Methods: This prospective nonrandomized interventional study included patients who needed a CVC from June 2017 to July 2018. The location of the CAJ was identified using a fluoroscopic technique. The following variables were measured: D1, the distance between the skin insertion point and the clavicular notch; D2, the vertical distance between the clavicular notch and the carina; and α, the vertical distance between the carina and the CAJ.

Results: A total of 70 patients were enrolled. The mean age was 65.5 ± 11.6 years and 62.9% were male. The mean D1 and D2 were 7.6 ± 1.4 and 7.0 ± 1.4 cm, respectively. The mean α was 4.4 ± 1.5 cm (95% CI 4.1-4.8) and it was not affected by demographic factors, such as sex, age, height or weight.

Conclusions: CVCs in adult patients can be placed near the CAJ using a simple formula: the distance between the skin insertion point and the clavicular notch + the vertical distance between the clavicular notch to the carina + 4.4 cm.

Keywords: Central venous catheter, fluoroscopy, cavoatrial junction

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Introduction

The recommended position of the central venous catheter (CVC) tip is between the distal third of the superior vena cava (SVC) and the cavoatrial junction (CAJ), or in high right atrium depending on the purpose and type of catheter (1). It is important to precisely target the CAJ, because venous thrombosis is more frequent when the CVC tip is located in the middle or proximal part of the SVC (2, 3).

Past formulas did not target the CAJ, therefore using those formulas may not reach the CAJ (4-6). The reason the previous formulas did not target CAJ was that cardiac tamponades were sometimes reported when catheters were placed close to the atrium (7). However, this kind of complication almost disappeared after using silastic tubes. Given the increased risk of venous thrombosis and repositioning when the catheter is not sufficiently inserted in the distal third of SVC or high right atrium, a new formula for targeting CAJ is needed.

In 2007, Ryu et al. reported that the CVC tip can be reliably placed near the carina level when it is inserted to a depth derived by adding the distance between the skin insertion point and the clavicular notch on the skin mark and the vertical distance between the clavicular notch and the carina on the chest radiograph (8). Based on this report, if the vertical distance from the carina to the CAJ is determined, the CVC tip can be placed near the CAJ by simply adding it to the previously described depth.

A chest radiograph, which is often used to identify the position of the CVC tip, is not appropriate to determine the exact location of the CAJ because the pericardium ascend alongside the wall of the SVC. Several techniques for locating the CAJ have been proposed including methods using computed tomography scans or cadavers (9-11). In addition, a fluoroscopic technique can be used, and the CAJ can be identified using only a relatively small amount of contrast media (12).

Based on the location of the CAJ, which is found fluoroscopically, this study aims to develop a formula to locate the CVC tip near the CAJ. In addition, other demographic factors were evaluated as to whether they were related to the vertical distance from the carina to the CAJ or not.

Materials and Methods

Patients

This was a prospective interventional study in a single center. The patients who required CVCs for a range of clinical reasons, such as major surgery or parenteral nutrition, were consecutively screened for enrollment from June 2017 to July 2018. Inclusion criteria were (1) age ≥ 18 years, (2) serum creatinine < 1.4 mg/dL at the time of enrolment and (3) patient consent. The patients with contrast allergy, a contraindication to radiation exposure, a history of open thoracotomy or bleeding tendency were excluded. Information on patient demographics including age, sex, height, weight, body mass index (BMI) and body surface area (BSA) was collected.

Each patient was given detailed information on the procedure and provided written consent. The study was conducted in accordance with the Declaration of Helsinki and was approved by the Seoul National University Hospital Institutional Review Board (1610-041-797).

Sample size

The distance between the carina and the CAJ was further identified in this study in comparison to the previous study which measured the distance between the skin insertion point and the carina (8). A study using cadavers reported that the distance was 5.3 cm (n = 39) with a standard error of 0.2 cm (11). A standard deviation (SD) was calculated to be approximately 1.3 using the above values. This study used angiography to directly measure this distance, a similar variation in the measurements was assumed. Target number was calculated using PASS (version 2005; NCSS LLC., Utah, USA). If the 95% confidence interval of the distance was set to 1 cm, the target number was 29 with an SD of 1.3. As previous reports did not show the demographic factors affecting the distance between the carina and the CAJ, we conducted research with around three times the target number, resulting in the inclusion of 90 subjects for the analysis of demographic factors such as height and weight.

Procedure

All procedures were conducted by four vascular surgeons. Before inserting CVCs, the distance between the clavicular notch and the carina (D2) was measured on a chest radiography (anteroposterior view in an erect position). The patient's head was turned to the left, and the right side of the neck was extended after lying down. After sterile draping was applied, the right internal jugular vein (IJV) was punctured using a 21-gauge needle (Micropuncture® access set; Cook medical LLC., Bloomington, USA) under ultrasound guidance. At this time, the diameter of the IJV was measured with ultrasonography. After insertion of a guide wire, the patient's neck was turned to the neutral position. The distance between the skin insertion point and the clavicular notch (D1) was measured using an aseptic ruler on the skin. Then, CVC was inserted to a depth derived by adding D1 and D2. The CAJ was identified using a maximum of 10 ml contrast media with C-arm fluoroscopic guidance (GE OEC 9000; GE Healthcare, Chicago, USA or OSCAR 15; KPI Healthcare, California, USA) while the patients were told to hold their breath after deep inspiration (Figure 1). The CVC tip was placed near the CAJ. The α was obtained by subtracting

[D1 + D2] from the total insertion depth (Figure 2).

Figure 1. Angiographic findings of the cavoatrial junction. Contrast media appears to be spreading at the atrium (arrow).

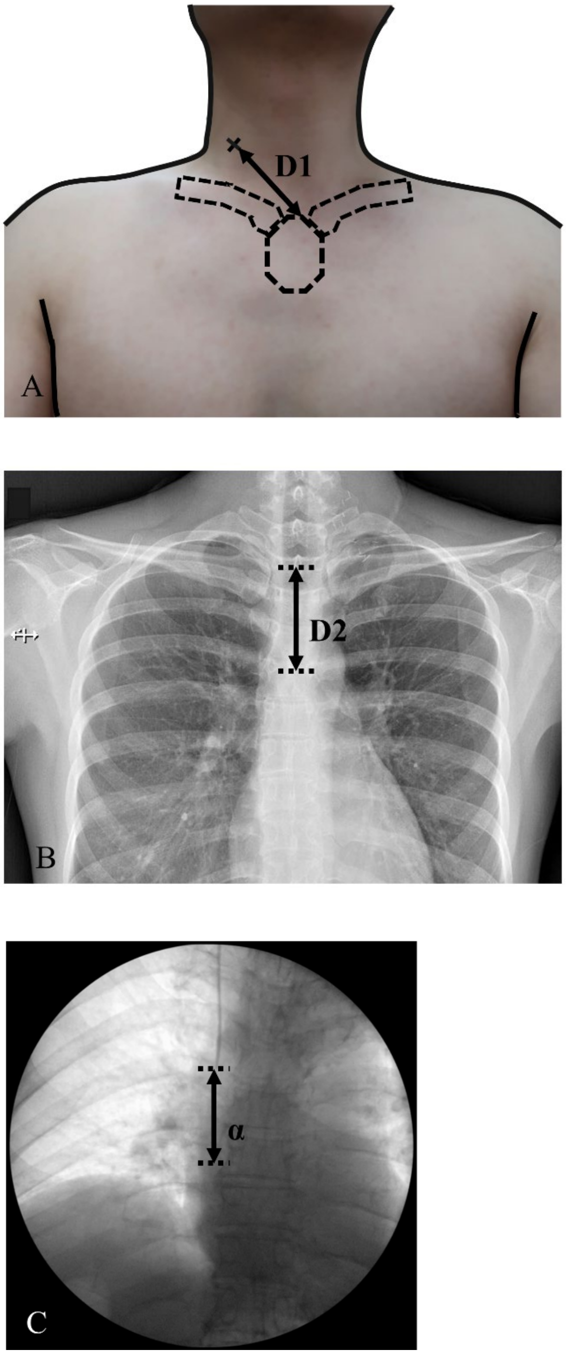

Figure 2. Illustration of the three measurements. A) The distance between the skin insertion point and the clavicular notch on the skin surface (D1), B) The vertical distance between the clavicular notch and the carina on a chest radiograph (D2), and C) The vertical distance between the catheter tip and the cavoatrial junction on C-arm fluoroscopy (α); total insertion depth = D1 + D2 + α.

Data analysis

Statistical analyses were performed using SPSS (version 23.0; SPPS Inc., Chicago, USA). The data were expressed as mean ± standard deviation (SD) values or as numbers and percentages. Continuous variables were compared using an independent-sample *t*-test. Univariate regression analyses were used for continuous variables to determine the factors affecting each measurement. A value of $P < 0.05$ was considered statistically significant.

Results

Data were collected from 70 patients and the mean age was 65.5 ± 11.6 years; the mean height was 162.7± 8.6 cm, and 62.9% (44/70) were male. Patient demographics are depicted in Table 1. All CVCs were inserted via the right IJV without adverse procedural events such as pneumothorax or CVC kink. CVC insertion depth can be expressed as the following formula.

[Total insertion depth
= the distance between the skin insertion point and the clavicular notch on the skin surface (D1)
+ the vertical distance between the clavicular notch and the carina on a chest radiograph (D2)
+ the vertical distance between the catheter tip and the cavoatrial junction (α) on C-arm fluoroscopy]

Measured distances are summarized in Table 2. The mean D1 and D2 were 7.6 ± 1.4 and 7.0 ± 1.4 cm, respectively. α was 4.4 ± 1.5 cm (95% CI 4.1-4.8). D1 and D2 were statistically significantly longer in male patients than females; however, there was no significant difference in α between male and female. The calculated distances using the above formula with α values of 4.4 cm were compared with the actual distances to reach the CAJ (Figure 3). The differences were less than 2 cm in 89% of patients and less than 1 cm in 46% of patients. In the univariate analysis, demographic findings including age, height, BMI and

BSA were not associated with α (Table 3).

Table 1. Demographics of patients

	Total (N=70)
Age, year	65.5 ± 11.6
Male (%)	44 (62.9%)
Height, cm	162.7 ± 8.6
Weight, kg	66.0 ± 11.1
Body mass index, kg/m^2	24.9 ± 3.5
Body surface area, m^2	1.7 ± 0.2

Data are expressed as mean ± SD or number of patients (percentage)

Table 2. Measured distances in male and female patients

Parameter (cm)	Total (N=70)	Male (n=44)	Female (n=26)	*P*
IJV diameter	1.9 ± 0.6	2.0 ± 0.7	1.7 ±0.6	0.058
D1, Distance from insertion point to clavicular notch	7.6 ± 1.4	8.0 ± 1.1	6.9 ± 1.6	0.002
D2, Distance from clavicular notch to carina	7.0 ± 1.4	7.5 ± 1.2	6.0 ± 1.1	<0.001
α, Distance from catheter tip to cavoatrial junction	4.4 ± 1.5	4.4 ± 1.6	4.6 ± 1.2	0.615

Data are expressed as mean ± SD. *P* values based on the Independent-sample *t*-test.

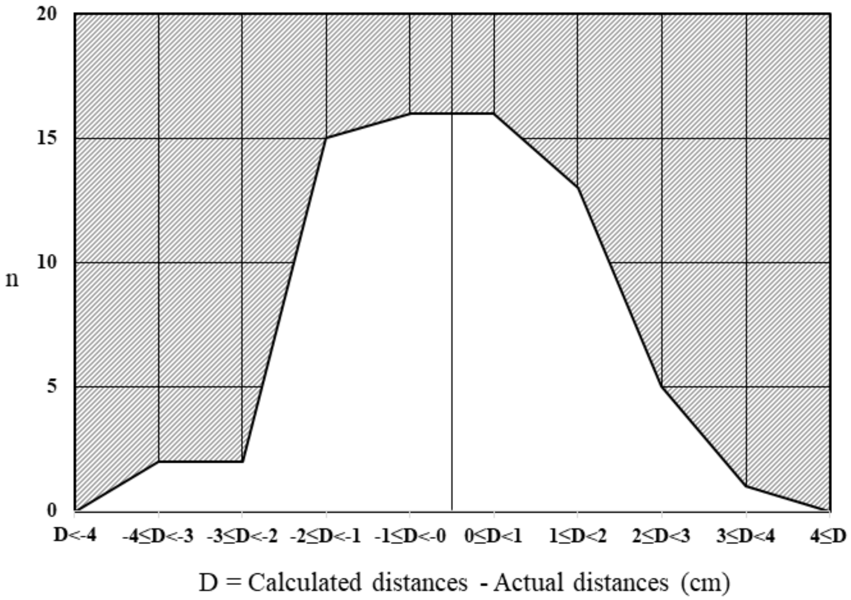

Figure 3. Distribution of the difference between the calculated insertion depth using α of 4.4 cm and the actual insertion depth to reach the cavoatrial junction.

Table 3. Correlation of measured distances and demographic findings

Variable	D1	D2	α
Age	0.031	0.332**	0.083
Height	0.227*	0.329**	0.037
Weight	0.319**	0.108	0.015
Body mass index	0.212*	0.123	0.009
Body surface area	0.273**	0.162	0.026

Correlation coefficients based on the simple regression analysis

*$p < 0.1$

**$p < 0.05$

Discussion

Current guidelines recommend that CVCs should be located in the distal third of the SVC or the high right atrium (1). Ryu et al suggested the formula to place CVCs near the carina (8). In this study, the vertical distance from the carina to the CAJ was measured using a fluoroscopic technique and it is 4.4 ± 1.5 cm (95% CI 4.1-4.8) in Korean adult patients. This value is not affected by demographic factors such as sex, height and BMI.

There are several formulas for optimal CVC insertion depth. In 1990, Peres *et al.* reported that the optimal distance of CVCs inserted via right external or IJV could be estimated by the formula; Height/10 (4). In 1993, McGee *et al.* showed that the average safe insertion depth was 16.5 cm for the majority of adult patients when CVCs were inserted via the left or right IJV or subclavian vein (5). Then in 1995, Czepizak *et al.* reported that Peres formula can predict the required distance of CVCs (6). At this time, considering the risk of cardiac tamponade, it is recommended to avoid placement of CVCs within the right atrium (13). However, Collier *et al.* reported that most cases (88%) of cardiac tamponade involve the use of non-silastic catheters (14). Since the introduction of CVCs made of silastic rubber, this kind of complication becomes extremely rare.

There are several possible problems related to catheter malposition. Cadman A *et al.* reported that venous thrombosis rate was 5.3% when the catheter tip was placed in the middle third of the SVC and 41.7% when in the upper third of the SVC or more proximal part. These were significantly higher compared to the venous thrombosis rate of 2.3% when the catheter tip was in the distal third of the SVC and atrium (2). Similar findings for venous thrombosis were presented by Ballard DH *et al*. They also found that catheters placed peripheral to the CAJ were more likely to be associated with tip repositioning. The repositioning rate was 0% (0/150) when the catheter tip was within the right atrium or the CAJ, and 11.3% (6/53) when it was within the high superior vena cava or the innominate/subclavian veins. Tip repositioning could result in the early removal of the catheters. Also, they reported a case of thrombophlebitis caused by catheter repositioning to the internal jugular vein, leading to septic embolism to the brain and subsequent death (3). In our experience, there was no case where the catheter had to be pulled back due to catheter malposition. According to the randomized trial of different distances for continuous renal replacement therapy conducted by Morgan D *et al.*, inserting longer (20 cm) catheters through the right internal jugular vein was not associated with more complications, such as atrial fibrillation and ventricular arrhythmia, compared to shorter (15 cm) catheter. The distance of the longer catheters used in this study is similar to the mean catheter insertion distance (19 cm) in our study. Moreover, they underlined that with longer catheters, 81% of the tips were located in the right atrium (15).

Several reports have described the distance from the carina to the CAJ using various methods. Albrecht *et al.* found that its mean distance was 5.3 cm with a standard error of 0.2 using cadavers (11). Mahlon *et al.* measured the distance using pulmonary computed tomographic angiograms from 112 patients. They reported it to be 40.3 mm with SD of 13.6 (10). In previous studies, the distance between the carina and the CAJ was not associated with demographic findings including age, sex, height, BMI and BSA. Under C-arm fluoroscopic guidance, the actual insertion depth to place the CVC tip at the CAJ was directly measured. Unlike methods using CT or cadavers, which only measured the distance between the carina and the CAJ, we could confirm the location of the catheter tip and the CAJ at the same position during the procedure. Kim *et al.* reported that the whole distance from the skin insertion point to the CAJ is 17.1 ± 1.7 (7). In the present study, insertion depth to place CVC tip near the CAJ was 19.0 cm which is slightly longer than that of the previous report. Because they only provided total distance from the skin to the CAJ, it was difficult to determine what caused this difference.

Some patients happen to take chest CT scans after they have inserted CVCs, so the information on the location of the tip could be collected prospectively. Further study could be carried out to evaluate how accurate this formula is. Another study is planned for peripherally inserted central catheters (PICCs), which are more frequently used than internal jugular catheters lately. Developing a formula to calculate the insertion distance to reach the CAJ will reduce the need for revision and increase patient convenience.

Our study has some limitations. First, the sample size for the trial was reduced from an original target of 90 to 70 subjects. Inserting catheters to the CAJ was not a complicated procedure, however, each operator had difficulty distinguishing the CAJ angiographically in the first few cases. All operators successfully detected it after a few cases. Considering learning curve, the initial five cases were excluded for each operator and finally the data from 70 patients were used for analysis. Second, according to the procedure protocol, after inserting a catheter to a depth derived by adding D1 and D2, the location of the

CAJ was identified angiographically. Previous studies have shown that the CVC tip is very close to the carina when inserted to this depth; however, we did not directly confirm this during the procedure. As reported by Ryu *et al* (7)(8)., the difference between α and the actual distance from the carina to the CAJ is expected to be very small, approximately 1 mm, however, this was not confirmed during the procedure. Third, our study population was restricted to the patients in Korean population, which could represent a smaller and thinner population, which may limit the generalizability of the formula.

Conclusion

Calculating the CVC insertion depth using measurements on the skin surface and chest radiography is intuitive and simple. The CVC can be placed near the CAJ using the following formula: Catheter insertion depth = the distance between the insertion point and the clavicular notch + the vertical distance between the clavicular notch to the carina + α. The mean α was 4.4 ± 1.5 cm (95% CI 4.1-4.8) and it is not affected by demographic factors. Considering that most CVCs are inserted at the bedside, our formula provides intuitive and practical information.

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요약 (국문초록)

합병증을 줄이기 위해 중심정맥도관의 끝을 대정맥−심방접합부나 심방 안에 위치시키는 것이 중요하다. 중심정맥도관을 피부삽입부와 빗장패임 사이의 거리와 빗장패임과 기관분기부 사이의 거리를 더한 만큼 넣으면, 도관의 끝은 기관분기부 근처에 위치하게 된다. 이런 사실을 바탕으로 중심정맥도관을 대정맥−심방접합부에 위치시키기 위한 삽입거리를 구하는 공식을 만들고자 하였다. 전향적 비무작위 임상시험을 시행하였고, 2017년 7월부터 2018년 8월까지 중심정맥도관 삽입이 필요한 환자를 대상으로 연속적으로 모집하였다. 대정맥−심방접합부의 위치는 수술용 투시유도 하에 확인을 하였다. 아래의 3가지 거리를 시술 중에 측정하였다: 거리 1, 삽입부와 빗장패임 사이의 거리; 거리 2, 빗장패임과 기관분지부 사이의 수직 거리; 거리 3, 기관분지부와 대정맥−심방접합부 사이의 수직 거리. 총 70명의 환자가 분석 되었다. 환자의 평균 나이는 65.5 ± 11.6 세였고, 62.9%는 남성이었다. 거리 1과 2의 평균값은 7.6 ± 1.4 와 7.0 ± 1.4 cm 였다. 거리 3의 평균값은 4.4 ± 1.5 cm (95% CI 4.1−4.8) 였고, 이 값은 환자의 나이, 키, 성별, 체중 등에 영향을 받지 않았다. 한국 성인에서 아래의 공식을 사용하여 중심정맥도관의 끝을 대정맥−심방접합부 근처에 위치시킬 수 있다. 총 삽입 길이 = 삽입부와 빗장패임 사이의 거리 + 빗장패임과 기관분지부 사이의 수직 거리 + 4.4 cm.

주요어: 중심정맥도관, 투시검사, 대정맥−심방접합부

학 번: 2018−21446